METHOD OF FORMING SOOT PREFORM

BACKGROUND OF THE INVENTION

FIELD OF THE INVENTION

5   The present invention relates to an improved method
of forming a pure silica soot preform on a starting rod
at a high yield rate and a high deposition rate by using
a VAD method (Vapour-phase axial deposition method) to
thereby produce an optical fiber preform.

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DESCRIPTION OF THE RELATED ART

       A silica glass of high purity, particularly a silica
glass article which is used for an optical fiber preform
is produced by a so-called vapour-phase synthesis method
15   in order to avoid mixing metallic impurities therein.
Namely, a liquid glass material such as $SiCl_4$ and $SiHCl_3$
is vaporized and gasified. The gasified glass material
is supplied into a flame which is formed with hydrogen
or hydrocarbon of high purity as a combustion gas and
20   high purity oxygen as a supporting gas, to thereby form
glass particles by flame hydrolysis and oxidation. Then,
the glass particles are deposited on a starting rod as
a target to form a soot preform. The soot preform is
vitrified at a high-temperature furnace, and thereby
25   the silica glass is produced. The VAD method or OVD method

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(Outside Vapour-phase Deposition method) is generally
employed as vapour-phase synthesis method. Hereinafter,
the soot preform for producing a silica glass by the
VAD method or OVD method consists of the starting rod
5   and the deposited glass particles on the starting rod.

A coaxial multi-tubular burner is generally used
as a burner for synthesizing flames. A deposition rate
of the soot preform is defined by increment of the weight
of the soot preform per unit time. In order to raise
10 the deposition rate of the soot preform, there is used
a so-called coaxial multiple flame burner. The multiple
flame burner produces first flame and second flame. The
first flame for synthesizing the glass particles
comprises a raw material gas of glass, a combustion gas
15 and a supporting gas. One or more flame is disposed on
the outer periphery of the first flame to heat the surface
of the soot preform where deposition takes place.

A protective tube for regulating an expanse of flames
and preventing a flutter of the first and second flames
20 due to disturbance is normally provided at the tip of
the burner. In this case, for example, it has been proposed
to control the expanse of flames by providing the
protective tube at a tip of the synthesizing tube for
decreasing a crack generation according to decreasing
25 a bulk density difference, which takes place where the

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soot preform starts to be deposited. The protective tube

has an opening end with a regulated diameter thereof.

(Japanese patent laid-open No. Hei.5-345621)

When the soot preform, which is formed by the VAD

5   method thickly on the periphery of the glass rod, having

a core is dehydrated and vitrified, many fine voids are

generated on the interface of the soot preform. In order

to avoid generating the voids, there has been proposed

a method for forming a soot preform by using a primary

10 burner and a secondary burner. The first layer of the

soot preform is formed on the outer periphery of the

glass rod of high purity by using the primary burner.

The first layer has the diameter twice or less than that

of the glass rod. Then, by using the secondary burner,

15 the second layer on the outer periphery of the first

layer is formed on the surface of the first layer (Japanese

patent laid-open NO. Sho.63-248734) with the temperature

of the interface between the glass rod and the first

layer at 900 - 1,000 °C.

20   In the VAD method, glass particles are been depositing

on the outer periphery of a target glass rod consisting

of a core or a core and a cladding, while the glass rod

is been pulling up.

In the method, a ratio of a diameter c of the soot

25 preform corresponding to the diameter b of the glass

rod (which includes the core and the cladding) must be kept constant under the condition that the bulk density of the soot preform is constant, so that the core diameter with respect to the diameter of the finally formed soot

5   preform is constant, since the ratio b/a of a core diameter a to a cladding diameter b of the glass rod is generally constant.

Incidentally, if the diameter of the soot preform becomes large, the deposition rate of the glass particles

10   to the soot preform becomes improved. The deposition efficiency of the glass particles is raising depending on increment of the soot preform diameter. However, in the case that the outer diameter of the soot preform is increased, the adherence of the glass particles to

15   an interface between the glass rod and the soot preform (Hereinafter, referred to as "the interface of the soot preform") and the heating of the interface of the soot preform becomes insufficient because of a limit to the expanse of flames of the burner. Consequently, voids

20   are generated at the time of consolidating the soot preform, and thereby a good transparent silica glass may not be obtained.

Further, there is provided with another method of raising the deposition rate for increasing an amount of the raw

25   gas material. If the amount of the raw material gas is

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increased, the formed glass particles are increased and
thus the soot preform is also thick. However, as the
flame for heating a deposition surface of the soot preform
remains unchanged, a lack of expanding the flames occurs.

5   Therefore, cracks might be produced in the early stage
of forming the soot preform, and the bulk density of
the outer layer portion of the soot preform is reduced,
thereby the soot preform becomes fragile. If the bulk
density of the interface of the soot preform is reduced,

10 a number of voids on the interface of the soot preform
(hereinafter, referred to as "the interfacial voids")
might be generated in the consolidated optical fiber
preform.

In order to prevent the interfacial voids, it is

15 an effective means to increase a quantity of flame by
enlarging the diameter of the burner or the diameter
of the open end of the protective tube at the step of
producing the soot preform. Even though the size of the
burner and/or the diameter of the opening end of the

20 burners are increased in the above-mentioned case, the
deposition area of the soot preform still remains
unchanged. Therefore, the yield rate of the raw material
gas is constant, but an absolute waste amount of the
glass particles is increased. Moreover, as oxygen gas

25 and hydrogen gas which do not contribute to heat the

soot preform are increased, it becomes non-effective as a whole.

Incidentally, in order to enlarge the soot preform without the generation of the interfacial voids, it is effective to introduce a small-sized burner as a primary burner for depositing the glass particles on the glass rod.

However, such a burner does not contribute to improving the deposition rate. Or rather the deposition rate becomes worse, if the glass particles are deposited only in the vicinity of the glass rod. For example, in case that a small-sized burner is used as a primary burner, the diameter of the soot preform formed by the small-sized burner is twice as large as that of the glass rod, the deposition amount of the glass particles deposited by the small-sized burner relative to the whole deposition amount is extremely small. The deposition rate in this case is substantially equal to or slightly increased in a case where only one secondary burner is employed.

Comparing with the case that only one secondary burner is employed, the amount of the raw material gas, combustion gas, and supporting gas is increased owing to adding the small-sized burner. Consequently, the yield rate of the raw material gas becomes less.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a method of forming a soot preform such that the deposition

5   of the glass particles may be formed at a high yield rate and a high deposition rate by employing two burners under certain conditions.

The above-object may be accomplished by the two-burners method of the present invention.

10   In a first aspect of the present invention, a method of forming a soot preform comprising:

forming a primary soot preform on an outer periphery of a glass rod by a primary burner; and

forming a secondary soot preform by a secondary

15   burner on an outer periphery the primary soot preform, wherein a diameter of the primary soot preform is set to be ranged from twice to five times of a diameter of the glass rod, and a thickness of the secondary soot preform is set to be ranged from 1.5 times to seven times

20   of that of the primary soot preform.

According to the first aspect of the present invention, it may be possible to maximize a performance of the primary burner with respect to that of whole burners.

When the ratio of the diameter of the primary soot

25   preform with respect to the starting rod are smaller

than two times, the contribution of the primary burner
is less with respect to the whole deposition. When the
diameter of the primary soot preform is seven times larger
than that of the starting rod, an interference of the

5   flame of the primary burner with that of the secondary
burner may be turbulent. Consequently, the deposition
efficiency or yield rate of the raw material gas is
considerably reduced.

It is preferable that the ratio between the thickness

10   of the primary soot preform and the secondary soot preform
is set in range from two times to five times of the thickness
of the primary soot preform, so that the deposition rate
is particularly improved.

When a diameter of an opening end of the secondary

15   burner is greater than that of the primary burner, a
surface of the soot preform heated by the secondary burner
is larger than that heated by the primary burner.
Consequently, deposition rate of the primary preform
and that of the secondary preform becomes better

20   respectively.

Here, the diameter of the burner can be defined
by two cases, the diameter of the burner at the tip,
or the diameter of a windshield or a protective tube
at the tip, if the windshield or the protection or the

25   tube is attached to the burner.

When the diameter of the opening end of the secondary burner is set in range from two times to five times of that of the primary burner, the deposition surface of the soot preform may be heated most efficiently.

5   When an angle between each axis of the burners and the axis of the glass rod is ranged from 45 to 75 degree, the surface of the soot preform formed by VAD method becomes most stably and the glass   particles deposition can be performed at high efficiency.

10   When a distance between center point of the glass particles deposition area by the primary burner and that by the secondary burners is one third of or greater than the diameter of the soot preform, the deposition by the VAD method is efficiently performed. If a distance between

15 the primary and secondary burner is shorter than the above-mentioned range, the flames formed by the respective burners interfere with each other, and thereby the deposition of the glass particles and the soot preform is not effective.

20   It is preferable that the distance between center point of the glass particles deposition area by the primary and that by the secondary burners is three times of or smaller than the diameter of the soot preform.

When a supply of a raw material gas to the primary

25 burner is stopped before a supply of the raw material

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gas to the secondary burner is stopped at a termination end of the soot preform, an excessive portion of the glass particles deposited by the primary burner is curtailed.

5   After supply to the primary burner is stopped, the secondary burner deposits the glass particles down to the stop line where the glass particles deposition by the primary burner was stopped.

Consequently, the deposition of the glass particles

10   is performed more efficiently without waste of the raw material and thereby the production cost is reduced.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1A is a schematic vertical sectional view showing

15   a condition in which two burners are used to deposit glass particles according to the invention;

Fig. 1B a partial enlarged view of soot surface where deposition takes place and to which the burner is directed according to the invention;

20   Fig. 2A is a schematic vertical sectional view showing a condition in which one burner is used to deposit glass particles according to a prior art, and Fig. 2B a partial enlarged view of soot surface where deposition takes place and to which the burner is directed according to

25   the prior art;

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Fig. 3 is an exemplary diagram showing the way to adjust the amount of glass material (in a circle) and a deposition surface (in a trapezoid) in the prior art; and

5   Fig. 4 is an exemplary diagram showing variations in the amount of glass material (in a circle) and a deposition surface (in a trapezoid) in time series when two burners are used to deposit glass particles in the prior art.

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DESCRIPTION OF THE PREFFERED EMBODIMENTS

A glass rod onto which glass particles are deposited by the VAD method is made at pre-processing such that it has a core, but the glass rod does not always have a cladding. Next, the glass particles are deposited on 15 the glass rod by the VAD method. Then, the soot preform is consolidated. A core diameter with respect to the outer diameter of the consolidated preform is determined, then. The ratio of the diameter of the consolidated preform 20 to the diameter of the glass rod is generally set in range from 2 to 7. In other words, 75 - 95% of the whole glass particles are synthesized at the step of depositing the soot preform. Therefore, in view of the productivity of the soot preform, the deposition step is important. 25 The deposition rate of the glass particles is dependent

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on the amount of the glass particles and the deposition efficiency on the deposition surface.

While the density of a silica glass is set at 2.2 g/cm^3, the bulk density of the soot preform is set in
5   a range from 0.2 g/cm^3 to 0.7 g/cm^3 and preferably from 0.2 g/cm^2 to 0.4 g/cm^3. This is because the soot preform becomes extremely easily broken at a low bulk density, whereas the soot preform is not effectively dehydrated at a high bulk density.

10   When the glass particles are deposited, in view of the bulk density, the outer diameter of the soot preform may normally set in range from 3.2 to 23 times, preferably from 4.1 to 23 times greater than that of the glass rod.

Glass particles have been deposited by using one
15   burner according to the conventional VAD technique. In this case, the deposition rate of the soot preform is raised by increasing (i) an amount of glass particles to be deposited and (ii) the efficiency of deposition on the deposition surface of the glass rod or the soot
20   preform.

Fig. 2A is a schematic sectional view showing conditions in which one burner is used to deposit glass particles in the prior art. Referred to Fig. 2A, the soot preform 202 is synthesized on the periphery of the
25   glass rod 201 by using a burner 203.

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Fig. 2B a partial enlarged view showing an enlarged deposit portion to which the burner is directed. Fig. 2B shows the deposition surface 204 of soot preform as viewed from the burner and a circle 205 corresponding

5 to an expanse of the glass particles formed by the reaction of the raw material gas spouted out of the burner on the deposition surface of the glass rod.

Fig. 3 shows a change of the amount of glass particles corresponding to the whole circular portion with respect

10 to the condition adjustment in time series (initial condition $\rightarrow$ A $\rightarrow$ B $\rightarrow$ C). Fig. 3 also shows a change of variation of the deposition surface which is shown trapezoid in shape. When the input of raw material gas is increased as shown in the condition A from the initial

15 condition to increase the amount of glass particles to be deposited, the diameter of the soot preform grows thick. As shown in the condition B and C, the relative position of the burner to the glass rod is adjusted so as to make the diameter of the soot preform constant,

20 since the diameter of the soot preform with respect to the core diameter has to be set at a constant ratio. Consequently, though the deposition rate of the soot preform certainly increases, a ratio of a portion contributing to the deposited amount with respect to

25 an expanse of the synthesized amount of glass particles

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becomes smaller. The portion contributing to the deposited amount is a portion overlapping the trapezoid with the circle in Fig. 3. And the expanse of the synthesized amount of the glass particles corresponding

5   to the input amount of the raw material gas in Fig. 3 is the whole circular portion. Therefore, it is not preferable in view of the yield rate of the glass particles.

On the other hand, the efficiency of deposition is increased by enlarging the deposition surface. The

10 deposition surface is enlarged by laying down the burners. In Fig. 1, the angle θ_1 and θ_2 is increasing according to laying down the burners. Fig. 4 shows conditions similar to those shown in Fig. 3. In the condition A, the deposition surface is enlarged by laying down the burner. In the

15 condition B, the input amount of the raw material gas is increased, while the deposition surface is kept as large as that of the condition A.

Consequently, the deposition rate of the soot preform is increased. Owing to enlarging the deposition surface

20 of the glass rod, however, flames for heating the interface of the soot preform become hard to reach the interface in comparison with the initial condition, and the temperature of the interface of the soot preform is decreasing, whereby the bulk density of the soot preform

25 is lowered. Therefore, voids are generated in the

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interface of the glass rod when the soot preform is
dehydrated and made transparent. This method is not
preferable because of generating the voids. In order
to suppress the generation of voids in the interface

5   of soot preform, Japanese Patent Unexamined Publication
Sho.63-248734 refers to "use of the primary burner for
forming a porous glass layer having a diameter twice
or smaller than the outer diameter of a high-purity glass
rod" (see Fig. 4(C) in this reference).

10   Though the problem of the fine voids generated on
the interface of the soot preform is solved by this method,
the amount of the soot preformed by the primary burner
is much less compared with the amount of the whole glass
particles after consolidating.

15   Therefore, when the primary burner is used according
to the above-mentioned prior art, the primary burner
does not contribute to the improvement of the deposition
rate of the soot preform directly. When we take an increase
of the input of raw gas material generated by the primary

20   burner into account, the ratio of the amount of deposited
glass particles to the total amount of raw gas material
is hardly raised. Therefore, the method is inefficient
in view of the yield rate of the raw material gas.

        In view of the below-described conditions, the ratio

25   of the sectional area of the primary soot preform to

the whole sectional area is 2.6%. And the ratio of the amount of the primary soot preform to the amount of the whole synthesized soot preform is 2.7%.

A bulk density of the glass particles deposited
5 to the periphery of the glass rod: 0.3 g/cm^3,

A ratio of the diameter of a preform after consolidation to the diameter of the glass rod: 4 times, and

A ratio of the diameter of the primary soot preform
10 to the diameter of the glass rod is two times.

As described above, contribution to improving the deposition rate of the primary burner is scarcely seen.

On the other hand, the present invention is effective as a method for realizing a yield rate of the raw material
15 while the above-mentioned problem is solved.

The method of the present invention is accomplished by the following conditions :

(i) $2 \times R1 \leq R2 \leq 5 \times R1$

(ii) $1.5 \leq (R3 - R2) / (R2 - R1) \leq 7$

20 wherein the diameter of the glass rod is R1, the diameter of the primary soot preform consisting of the glass particles formed by the primary burner is R2, the diameter of the secondary soot preform consisting of the glass particles formed by the secondary burner is
25 R3, a thickness of the soot preform deposited by the

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secondary burner is "(R3-R2)/2", and a thickness of the

primary soot preform formed by the primary burner is

"(R2-R1)/2".

In Fig. 1A, the soot preform 102 is formed on the

5 periphery of the glass rod 101 by using a secondary burner

103 and a primary burner 104. In the above-mentioned

conditions, it is preferable that a thickness of the

secondary soot preform is set in range from 2.5 times

to 5 times of the thickness of the primary soot preform.

10   Referred to Fig. 1B, the large circle 106 shows

the expanse of the glass particles formed by the secondary

burner, in other words deposition area of the secondary

burner. And, the small circle 107 shows the expanse of

the amount of the glass particles formed by the primary

15 burner, in other words deposition area of the primary

burner. The trapezoid potion 108 shows the deposition

surface of the soot preform in Fig. 1B. The portion

actually contributing to the deposition of the glass

particles by the primary and secondary burners is a portion

20 which overlaps the large circle 106 and small circle

107 with the trapezoid portion 108. A portion 105, which

does not overlap the large circle 106 and small circle

107 with the trapezoid portion 108, is corresponding

to a waste amount of the glass particles. A distance

25 T describes the distance between the center point of

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the large circle 106 and the center point of the small

circle 107. Referred to the Fig. 1A, an angleθ_1 between

the axis 104a of the primary burner and the axis 101a

of the glass rod is preferably set in the range from

5 45 to 75 degrees. An angle θ_2 between the axis 103a of

the secondary burner and the axis 101a of the glass rod

is preferably set in the range from 45 to 75 degrees.

Embodiments of the present invention are described in

detail; however, the descriptions herein are not intended

10 to limit the scope of the present invention.

(Example 1)

A raw material gas ($SiCl_4$), H_2 and O_2 is used to

deposit the glass particles under the following

conditions of depositing the glass particles.

15 Burner: two coaxial multi tubular burners (the ratio

between the diameters of the opening ends (secondary

burner / primary burner) is 3.3.)

A diameter of the glass rod: 30 mm.

A diameter of the primary soot preform: 100 mm.

20 A diameter of the whole soot preform formed by the

primary and secondary burners: 260 mm.

Distance T between the center points of the expanses

of the glass particles deposited by the primary burner

and secondary burner respectively: 200 mm.

25 The results are shown as follows:

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Deposition rate of the soot preform formed by the primary and secondary burners: 31 g/min.

Growth rate of the soot preform formed by the primary and secondary burners: 95 mm/min.

5   Yield rate of the raw material gas: 55%.

(Comparative Example 1)

Except that the following conditions are adopted, the glass particles are deposited under the same conditions in Example 1.

10   Burner: one coaxial multi-tubular burner (a burner angle of 60°, which is formed between the glass rod and the burner.)

A diameter of the soot preform: 260 mm.

The results are shown as follows:

15   Deposition rate of forming the soot preform: 22.0 g/min.

Growth rate of forming the soot preform: 85 mm/min.

Yield rate of the raw material gas: 50%.

The length of a "non-effective portion" at the
20   termination end of forming the soot preform in Example 1 is 1.3 times greater than that in Comparative Example 1. Here, "non-effective portion" means a tapered potion in which the diameter of the soot preform is descending.

(Comparative Example 2)

25   Except that the following conditions are adopted,

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glass particles are deposited under the same conditions in Example 1.

Burner: two coaxial multi tubular burners (the ratio between the diameters of the opening ends (secondary

5   burner / primary burner) is 5.0)

A diameter of the primary soot preform: 50 mm.

The results are shown as follows:

Deposition rate of the soot preform by the primary and secondary burners: 22.3 g/min.

10   Growth rate of the soot preform by the primary and secondary burners: 85 mm/min.

Yield rate of the raw material gas: 42%.

(Comparative Example 3)

Except that the following conditions are adopted,

15   glass particles are deposited under the same conditions in Example 1.

Burner: two concentric multi tube burners (the ratio between the diameters of the opening ends (secondary burner / primary burner) is 2.0.)

20   A diameter of the primary soot preform: 150 mm .

The results are shown as follows:

Deposition rate of the soot preform by the primary and secondary burners: 30 g/min.

Growth rate of the soot preform by the primary and

25   secondary burners: 90 mm/min.

Yield rate of the raw material gas: 44%.

(Example 2)

Except that the following conditions are adopted, glass particles were deposited under the same conditions

5   in Example 1.

Burner: two coaxial multi tubular burners (the ratio between the diameters of the opening ends (secondary burner / primary burner) is 3.3.)

Distance between center points, where the glass

10   particles are deposited by the primary and secondary burners: 80 mm.

The results are shown as follows:

Deposition rate of the soot preform by the primary and secondary burners: 30 g/min.

15   Growth rate of the soot preform by the primary and secondary burners: 90 mm/min.

Yield rate of the raw material gas: 50%.

(Example 3)

Except that a supply of the raw material gas supplied

20   to the primary burner is stopped 30 minutes before estimated time when the formation of the soot preform is terminated, glass particles are deposited under the same conditions in Example 1.

As a result, while the deposition rate of the

25   "effective portion" remains unchanged, the length of

the non-effective portion at the termination end is

reduced to the same length in Comparative Example 1.

Here the "effective portion" means a portion in which

the diameter of the soot preform is constant.

5   In forming the soot preform by the two-burners method,

a high yield rate of the raw material gas and a high

deposition rate of the soot preform is accomplished by

the present invention.

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